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Title: How Important is Oblique Vision in Aviation?

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14. ABSTRACT
(A) We propose a basic system layout that combines with the microdisplay for contrast sensitivity function measurement. The optical components need to be modified to eliminate the aberrations. (B) We made the power and control electronics for this system that increase the capabilities to build the specific deformable pattern by our self. (C) We measured the interferences patterns for the deformable mirror and build the influences matrix (D) We did NOT complete the system due the limited resources. It is believed that without appropriate financial management, it is not easy to complete the whole system in schedules. (E) We have measured the interferences patterns of the deformable mirror with our driving power system. Preliminary results indicate that there might be some problems for the driving issues in the deformable mirror that leads to the slower or breakdown of the elimination of the aberration. Also, the reason that the optical components in this layout can not work perfectly is due to the large aberrations near the camera lens of the CCD and also part of the relay system. A modified design is accomplished.

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<u>CONTENT OF REPORTS</u>:

(1) Background

It has long been appreciated that vision is limited by both optical and neural factors, but that only optical factors can be easily and effectively manipulated. Chief among these are spherical refractive error and astigmatism. Other errors that are not corrected for in human vision (but that are corrected for in optical instruments) include chromatic aberration and coma. Recently it has been suggested that correcting for as much error as possible would improve vision, and in some cases yield supernormal vision (Liang et al., 1997; Yoon & Williams, 2002). It is possible to do this using adaptive optics (AO) that make use of wavefront sensing, and AO is now being built into equipment ranging from astronomical instruments to visual refractive surgical instruments. Some of the effects of such corrections can be predicted, but because humans evolved with these optical aberrations and may have taken them into account in the evolving design of the human visual system, some effects must be verified by experiment.

Wavefront correction may affect vision in various ways. One is to increase acuity by rendering visible the highest spatial frequencies (the finest details) in an image. Another is to increase the contrast of each spatial frequency in an image to the maximum extent possible. Generally, human visual acuity is limited by the highest spatial frequency that can be sampled by human photoreceptors. Foveal cones are tightly packed with 30 sec of arc separation (between cone centers), which yields a Nyquist (limiting) frequency of 60 cycles/deg, corresponding to an acuity of 20/10. Since many young people – including pilots – have acuities approaching these limits, or can be corrected to this acuity using standard techniques, one might question the utility of further correction. However further correction does yield higher contrast throughout the spatial frequency visible range and might therefore be useful (Liang et al., 1997).

But not necessarily. Take chromatic aberration for example. A complicated optical system is needed to focus on all wavelengths simultaneously, and human optics are not set up to do this. Consequently, when medium wavelengths are in focus, very short and long wavelengths may be out of focus by as much as half a diopter. In theory, when you look at a white dot on a black screen, you should perceive a hazy halo consisting of the blues and reds that contribute to the dot. However, generally you would not see this halo because human form systems are not very sensitive to fine details of short or long wavelengths and because sensitivity to the blur circles is reduced by the Stiles-Crawford effect (Alpern, 1990). Thus, chromatic aberration does not affect acuity very much. It should affect contrast sensitivity however, and it does; under conditions when chromatic aberration is avoided, contrast sensitivity is somewhat improved (Yoon & Williams, 2002). Does this mean that chromatic aberration in the visual system should be eliminated? Probably not. It turns out that humans use chromatic aberration as an important clue to drive accommodation (Fincham, 1951; Flitcroft, 1990; Kruger & Pola, 1986; Kruger et al., 1993; Kotulak et al., 1995), so eliminating chromatic aberration would be detrimental to perception of dynamic natural images.

What about correcting for higher order monochromatic aberrations, like spherical aberration and coma? Coma is essentially an aspect of spherical aberration (although the two are mathematically independent because of the deliberate way that they are computed using orthogonal polynomials). In essence, when objects are imaged though the periphery (e.g. far from the optic axis) of a lens or mirror, the most peripheral ends of an object are displaced relative to the near ends. In astronomy and photography, a spherical object located in the periphery of the optical field will be distorted into a comet shaped object – hence the name 'coma' (see Fig. 4). Humans are not aware of coma in their own visual system because acuity is so poor in the peripheral visual field; however, coma does reduce available contrast. One potential consequence of correcting for defects of peripheral vision is aliasing. The sampling properties of the peripheral visual field are rather well matched to optical abilities of the uncorrected visual apparatus. Since we have no way to increase neural sampling, we might expect that a peripheral optical correction would introduce sampling artifacts. Another problem is that some evidence suggests that many subjects with very high acuity also have somewhat larger amounts of higher order aberrations, especially coma.

The U.S. Navy has reported a correlation between high acuity and vertical coma in a study of 73 pilots (Schallhorn, 2001). These results could be either a statistical artifact or an optical artifact of combining vertical coma with the vertically oriented letters on their high contrast eyechart (Schallhorn, 2001) and it could be confounded by pupil size not being controlled in these studies. They also could be due to neural feedback akin to that found in chromatic aberration studies.

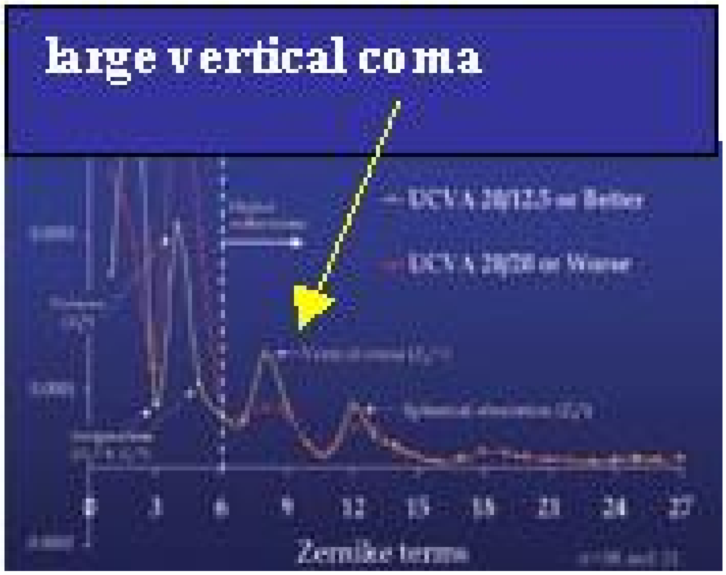

Figure 1. From Schallonhorn (2001). Plot of Zernike terms in subjects with very high acuity shows an unexpectedly large vale for the coma term.

At the Taiwan National Defense Medical Center/Tri-Service General Hospital (NDMC/TSGH) Eye Clinic, we independently found a similar result in a preliminary study using 11 transport aircraft pilots. The data, shown below, are the predicted Modulation Transfer Function (MTF) – autocorrelation of the pupil function defined by the optical aberrations in their eyes. For the purpose of illustrating the coma terms, only 3rd order and some 4th order aberrations were used. Fig. 2 shows the MTF from 18 normal subjects with varying amount of near-sightness and astigmatisms but all correctable to 20/20. Modulations at 10 cy/deg (20/60) can be estimated to be 0.37 and 0.39 for tangential and sagittal, respectively. On the other hand, Fig. 3 shows a tangential modulation of 0.27 and sagittal modulation of 0.36 for our pilots. Since only an unequal magnitude between vertical & horizontal comas could separate the tangential from the sagittal curves, the lower tangential MTF from our pilots indicates a larger vertical coma (depressed modulation) than normal. There seems to be a normal amount of horizontal coma in our pilots similar to Schallonhorn's report.

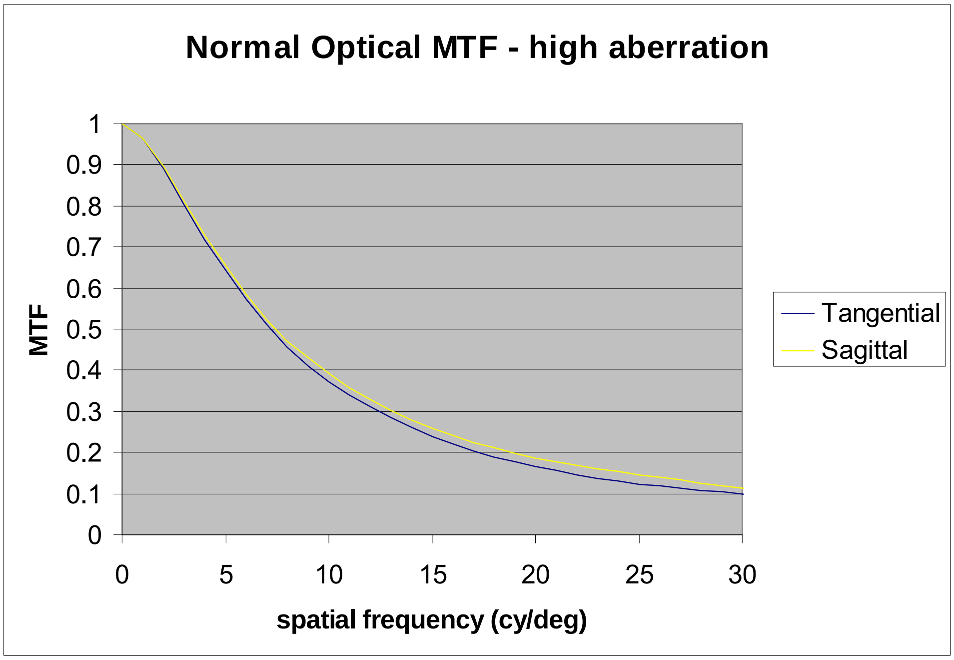

Figure 2. A plot of the average normal MTF calculated from optical aberrations measured in the eye (18 subjects). The plot shows equal modulation between tangential and sagittal curves due to equal vertical and horizontal comas.

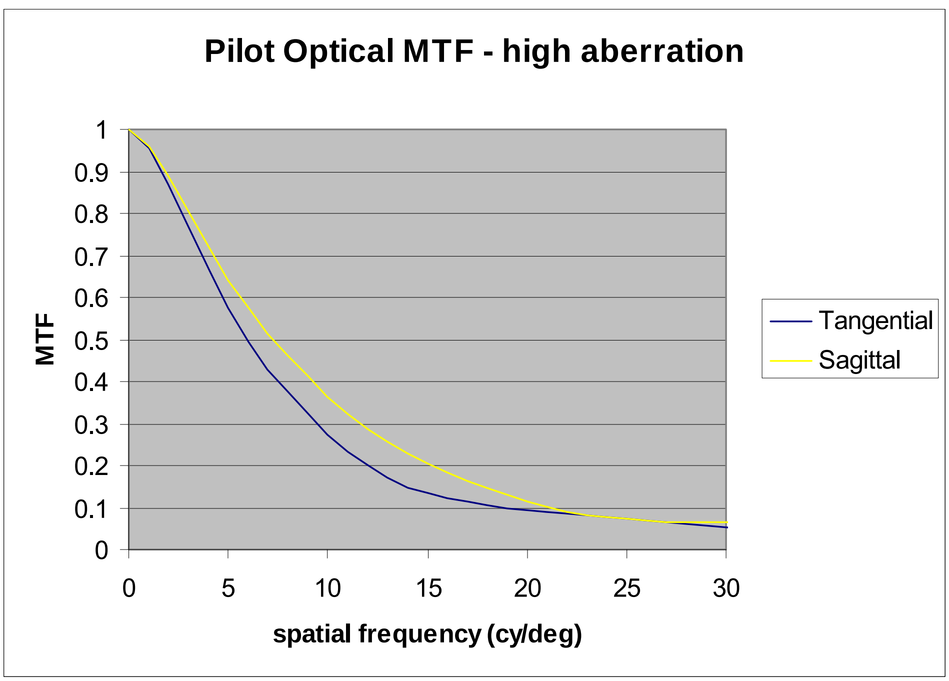

Figure 3. A plot of the average pilot MTF (11 pilots). On average, pilot with excellent uncorrected vision had slight elevated amounts of vertical coma.

(2) Proposed Research

Aims

These results raise three questions, which should be addressed:

1. What effects does wavefront manipulation of coma have on visual performance? Using the Zernike polynomial approach we can mathematically separate the various sources of optical error from each other. We can then use wavefront correction to selectively manipulate coma and find out three things:
    i. In subjects with very high acuity and high coma, does eliminating coma reduce acuity? Fig. 4 shows the aberrated images of a letter E with simple defocus and vertical coma. Does spreading energy out in the oblique meridian favor target discrimination in the aviation environment? We hope to study its benefit in this project.
    ii. In subjects with less than optimal acuity, can acuity be manipulated by manipulating coma?
    iii. What effect does manipulating coma have on contrast sensitivity? Does it vary from the effect that would be predicted from the optical modulation transfer function, implicating neural mechanisms?

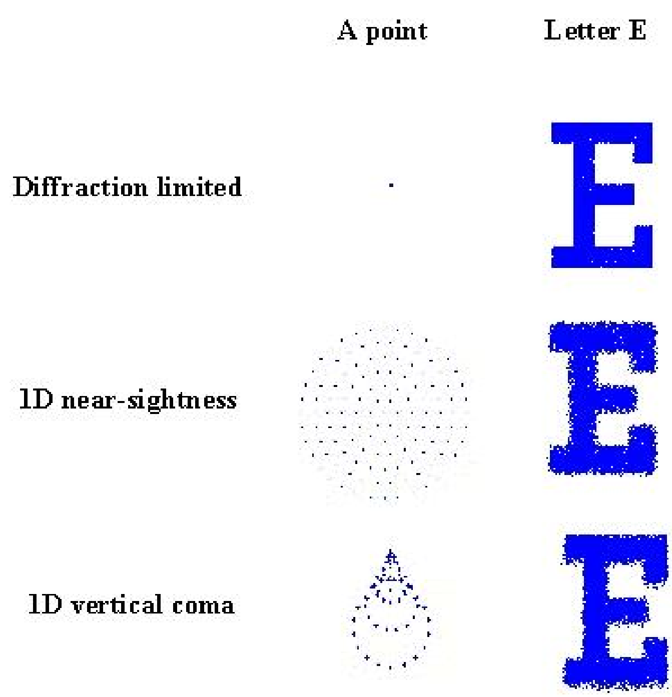

Figure 4. Aberrated image of a point and letter E. Vertical coma selectively blurs the image more in the oblique meridian than defocus (near-sightness), which has uniform blurs in all meridians (oblique as well as lateral).

2. How does coma in the eye interact with electroptical interfaces? To study this, we would combine a night vision goggle with the adaptive optics system and measure the effects on acuity and contrast sensitivity.

3. What effect does LAISK have on coma? In principle, this question could be answered using clinical instruments already acquired by the Eye Clinic. However, these instruments need to be independently verified by calibrating against a standard. NDMC/TSGH's preliminary evaluation of some of the clinical instruments on the market found that they gave variable and unrepeatable readings (see Fig. 5 below). This could be due to unreliable hardware design or overly restricted/unfriendly testing procedural

requirements. Again, adaptive optics would provide an objective standard because it would measure the absolute performance via wavefront sensing.

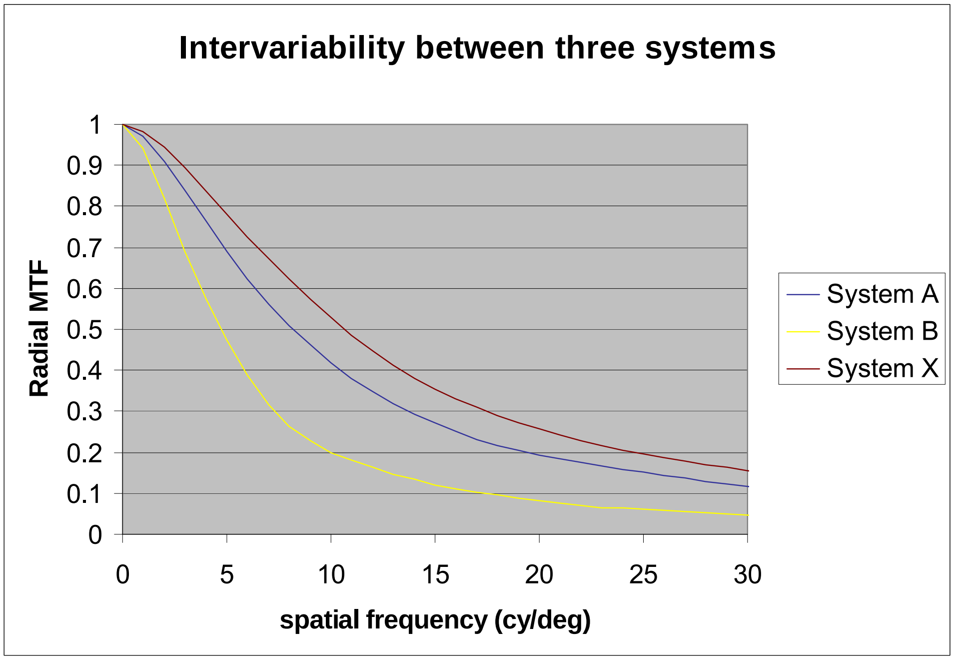

Figure 5. A plot of the average radial MTF from 18 subjects between three commercial aberratometers. Clearly, there is a large amount of variability between systems.

Apparatus

To accomplish the above work, we need to build an adaptive optics system based on wavefront reconstruction. A suitable system is not available off-the-shelf, but has been described in sufficient detail in the literature (Liang et al., 1997; Liang & Williams, 1997, Hofer, et al., 2001) – see Fig. 5. The essential elements of this system are a wavefront sensor and a deformable mirror, linked together by computer control. All the major components needed for the apparatus will be procured by the Taiwan Industrial & Technology Research Institute's OptoElectronics & System Laboratories (ITRI/OES) on behalf of the National Defense Medical Center, the organization responsible for this project. ITRI is located in the famed Shin-Chu Industrial Park, northwest of Taipei. OES will also engineer, assemble, and test the complete apparatus for this project. Dr. Chung-Jen Ou, who just completed a one-year sabbatical at the Oxford University in United Kingdom on optical design and modeling including adaptive optics, will be the lead engineer in charge of this research & development effort. He will be supported by electro-optical and mechanical engineers from the Optical Design & Components Division. Its departmental manager, Dr. Hoang-Yan Lin, will have the overall responsibility for the completion of this effort. Dr. Lin is a seasoned engineer who has been involved with a number of multi-million dollar optical and display projects. This effort will also receive corporate support and visibility from its General Director, Dr. Yung S. Liu. During his tenure at the General Electric Research Lab, Dr. Liu led the pioneering corneal ablation research program that provided the roadmap and impetus for recent advances in refractive surgery. His extensive knowledge and past experience in this particular field as well as his oversight participation will ensure the success of this effort.

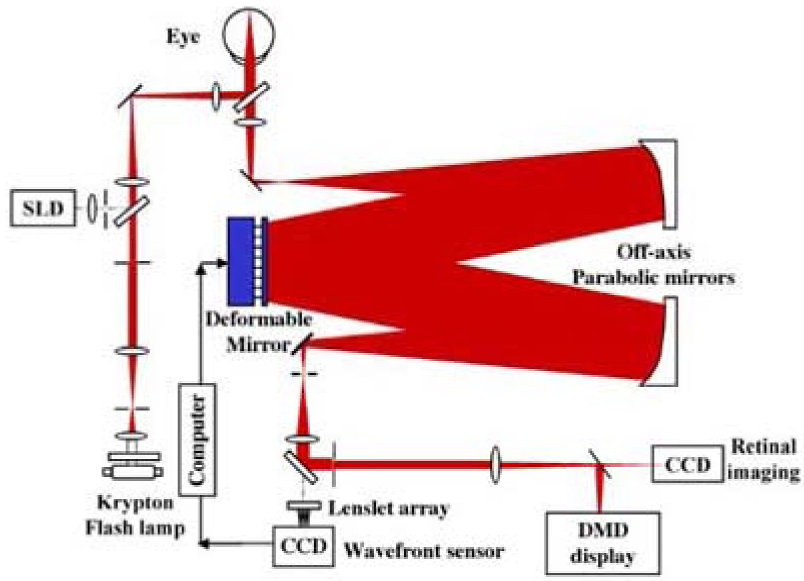

Fig. 5. Second-generation adaptive optics system (Hofer, et al., 2001). See APPARATUS Section for details.

Wavefront Sensing.

The wavefront sensor is described in detail by Williams and his collaborators (1997 and 2001). It consists of an eye safe laser, a close packed array of lenslets, and a CCD array. The laser is directed through the eye's optics onto the retina, which reflects the light back. At the pupil, the reflected wavefront is imaged by the lenslet array, which is optically conjugate to the pupil plane. Each of the individual lenslets is sampling the local slope of the wavefront. This sampling is digitized at the CCD array. From this array of slopes the wavefront is reconstructed by a least squares fit to a Zernike polynomial series.

Adaptive Compensation.

The results of the above analysis are used to drive a deformable mirror. One such mirror, available from Xinetics, Inc., consists of an aluminized glass plate with 37-97 piezoelectric actuators mounted in a square array on the back surface. Each actuator range of motion is broken into 4096 steps (12 bits) and the mirror is optically conjugate to the pupil and lenslet array. The subject's pupil is dilated and she views the image in the mirror while a bite bar controls her head position. Compensation is by closed loop feedback on each loop the actuator positions are adjusted until the RMS wavefront error converges on a minimum. Liang et al. reported that this takes 10-20 loops. Hofer et al. reported that a closed loop bandwidth of 0.8Hz was achieved and is minimally required to compensate for the eye dynamic changes due to accommodation. For this project, we will also test the feasibility of substituting the electromechanical control of deformable mirror with an electro-optical LCD for optical path length manipulations by modulating the phase of the convergent beams. This ought to increase the bandwidth of the adaptive compensation loop, thus improving overall efficiency of the system. Also, the smaller LCD has the potential to effect the system miniaturization required for clinical usage and acceptance. Various high-performance phase-modulated LCD would be tested for this project. One potential candidate is the Hamamatsu Phase Modulator, which costs US $6K a piece. It had successfully undergone qualification testing for manufacturability by our sister division within the ITRI/OES for another application. We will procure at least one test article for our own evaluation along with other commercially available phase modulators. The one that is best suited for our oblique vision study requirement will be integrated into the final assembly.

Quantification of Eye Quality and Visual Effects

The Zernike polynomial fit to the wavefront sensor output provides a detailed specification of eye quality. The second order polynomials quantify refractive error and astigmatism. Slightly higher order terms include spherical aberration (4^{th}) and coma (3^{rd}). Liang et al.'s approach is sufficient to quantify the first 65 Zernike polynomials, which provide all of the 1^{st} through 10th order terms. In practice, they found that corrections beyond the fourth order did not noticeably improve image quality.

There are several ways to study the effects of adaptive optics on vision. One of the simplest is to use the system to directly image the retina. This provides the clinician with an immediate check on whether the system is working; the retinal image is vastly clearer in this format than the image provided by an ophthalmoscope, which corrects only for simple refractive error. For quantification of perceptual effects, we intend to use acuity and contrast sensitivity. Because the preliminary studies that we addressed above use acuity, all of our experiments will as well. If practical in the clinical environment we are using, we will also measure contrast sensitivity (detection thresholds for sine-wave luminance gratings of various spatial frequencies).

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(3) Objectives

The goal of this research is to clarify an important problem that has implications for both clinical and applied vision in aviation. It has long been appreciated that vision is limited by both optical and neural factors, but that only optical factors can be easily and effectively corrected for. Chief among these optical factors are spherical refractive error and astigmatism. Recent advances in wavefront sensing and adaptive optics make it possible to correct for other optical errors as well, both in optical interfaces, and in the eye itself, via refractive surgery. What is unclear is whether all of these errors should be corrected for. It is possible that some errors have no effect on vision and that others have unforeseen benefits. Here we will explore the effect of correcting for a particular optical error – coma – which is a potential problem for peripheral vision. It is well known that peripheral vision is very important for aviation.

(A) The objective of this research is to develop an adaptive optical system that can eliminate or introduced specified aberration terms, and to study the effects of these aberrations terms to the vision.
(B) This research also try to study the possibilities of the building the related system in this local area, as well as for the commercialized.

Adaptive Optics (AO) is a widely used technique to enhance the performance of optical systems by actively compensating the aberrations. Varieties of devices for wave-front correction have been developed for AO [1][2][3]. AO use a spatial light modulator (SLM) to change the wavefront from an illuminated object, such that the image qualities from that object can be improved. Figure.1 give a functional block diagram for AO technology. At the very beginning, AO was used in astronomy to compensate the effects of atmospheric turbulence in images from large telescopes, and for the military applications. Due to the commercialized hardware and device is available, this techniques becomes an promising instruments for the medical research, such as the correction of the microscopy image, correction of the human eye aberrations etc.

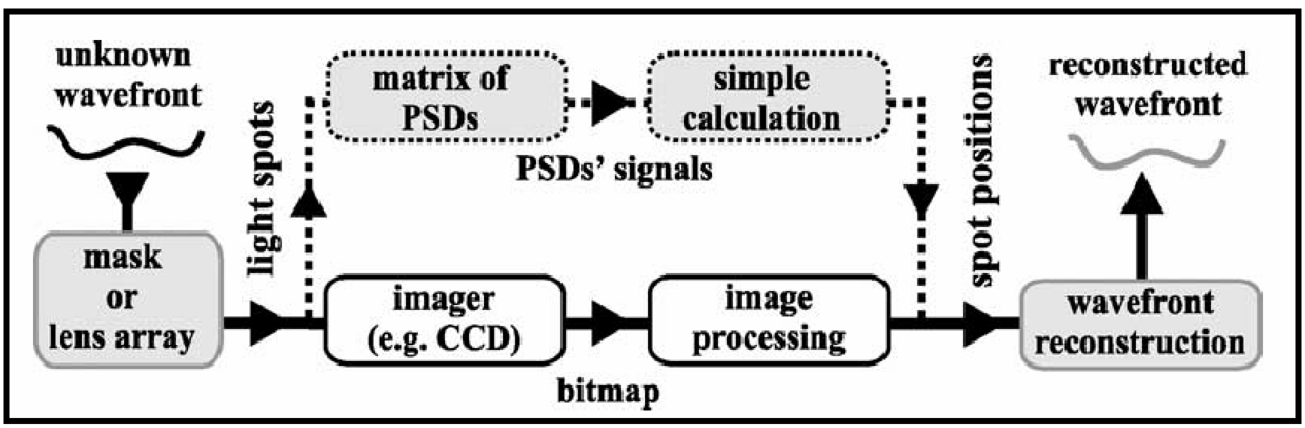

Figure.1 Function block diagram of AO system

In the context of ophthalmic applications, there are a lot of research on the correction and elimination of the aberration of the human eye for the past several years. Smirnov [4] first suggested that using AO technology to correct the aberrations of the human eye. After that, the using of a segmented mirror to correct astigmatism [5] and a speckle interferometer technique [6] were the applications of AO in ophthalmic applications. For the past several years, static corrections of the human eye aberrations were demonstrated by using MEMS SLM [7] or LC SLM [8]. Due to the dynamic nature of the ocular aberration [9], real time aberration correction becomes an essential task to obtain a reasonable correction of the aberrations. Several real time AO systems for this purpose that use DM were recently reported [10][11][12].

At the present moment, the COST of commercialized AO system is still high, and it does not meet the long-term prospect for TSH to buy such AO system without cooperated with local company in Taiwan. Therefore, it is the original intention from TSGH that to establish the AO systems for this AOARD project. Table.1 list four modules in an AO system.

No.	MODULE	DESCRIPTION
1	Light Source Module	Provide the suitable wavelength and intensity for the medical purpose
2	Wavefront Sensing Module	Measure the wavefront
3	Wavefront Correction Module	Correct the high order aberration of the human eye
4	Computation & Control Module	Calculate the results and send the control signals to the SLM

Table.1 Functional module in AO system

A typical optical system for these functional modules is present in figure.2 [13]. The most important component in AO system is the phase modulation SLM. According to the literatures, using DM is a suitable solution for eliminating the high order aberration of the human eye. This is our approach at the present moment. In this project, we will also contact with the local RD units or suppliers on the key components. Components from the local companies will be the first choice to reduce the cost and development time for the further researches and system integration.

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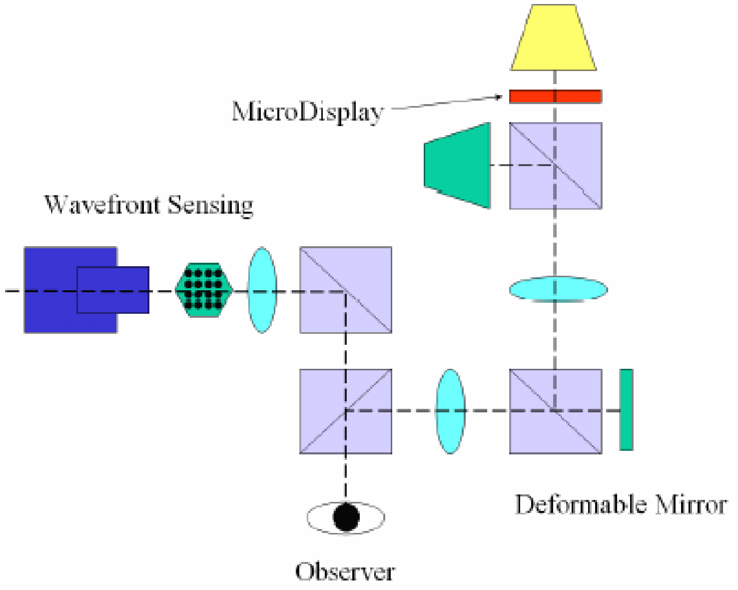
(4) Status of effort

(A) We first study various kinds of architectures.
(B) A system layout is design for this project.

(C) The following figures are the schematic layout of the adaptive system in our study. The purpose of this system is to correct the high order human eye aberrations. During the correction (or introduced) of the human eye aberrations, it is required to precede the contrast test chart exam to study the vision qualities.



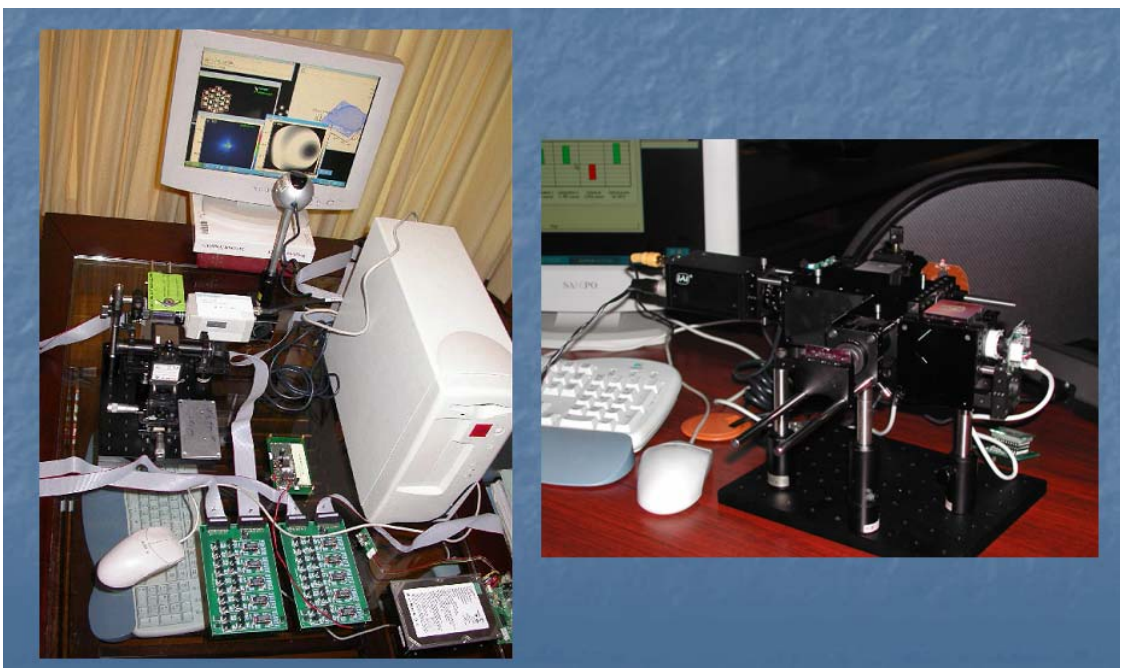


Figure.1: System Layout

(D) In this optical system, we use the microdisplay device to project the specific image patterns to the human retina.

(E) Several types of panels system had been introduced for the present apparatus to study the feasibilities of this kind of exam procedures.

(F) At the present moment, we can not complete this system under limited AOARD budget. The AOARD budget were for two deformable mirrors, driving software, H-S mask and personal labor fee. Rest apparatus were provide by the subcontractors without any funding.

Testing for Deformable Mirror

In order to ensure the performance of deformable mirror used in this project, we authorize the Industrial Technology Research Institute (ITRI) to test the optical wavefront generated by the mirror. And using the testing results we can analysis the relationship between the generated wavefront and the input control voltage.

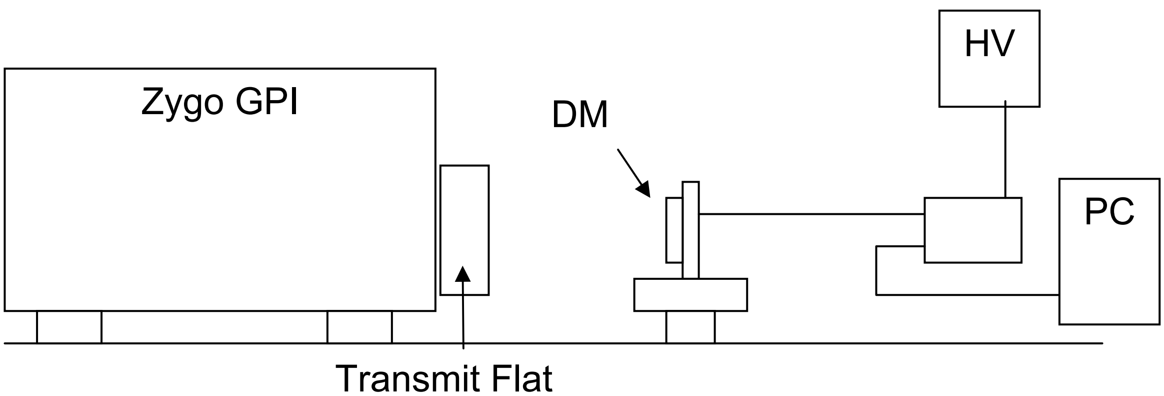
Testing method

In ITRI, the engineer using commercial interferometer (Zygo GPI system) which is 4 inch diameter Fizeau type interferometer, and widely used in optical testing. The calculation software also comes from Zygo. And it can calculation the wavefront parameters like P-V, RMS, Zernike coefficient, etc. In the testing we will focus on the Zernike coefficient of the generated wavefront and at the same time we can check each channel in the deformable mirror.

Before the testing, the engineer first check the connection between the channel and the pin ID. After that using the LabView to control the deformable mirror. At the beginning we control the High-Voltage control board to produce the reference high voltage about 200 volts, and we using the software to control each channel at the zero signal level, than using the interferometer to test the initial wavefront of the mirror.

After that, we control each channel (total 37 channels) at 4 different signal level 63, 127, 180 and 255 and then recording the 36 terms Zernike coefficient for each different signal level and different channel.

Testing System Layout



Testing result

At the initial state, the wavefront performance of the deformable can be described using following parameters: P-V and RMS

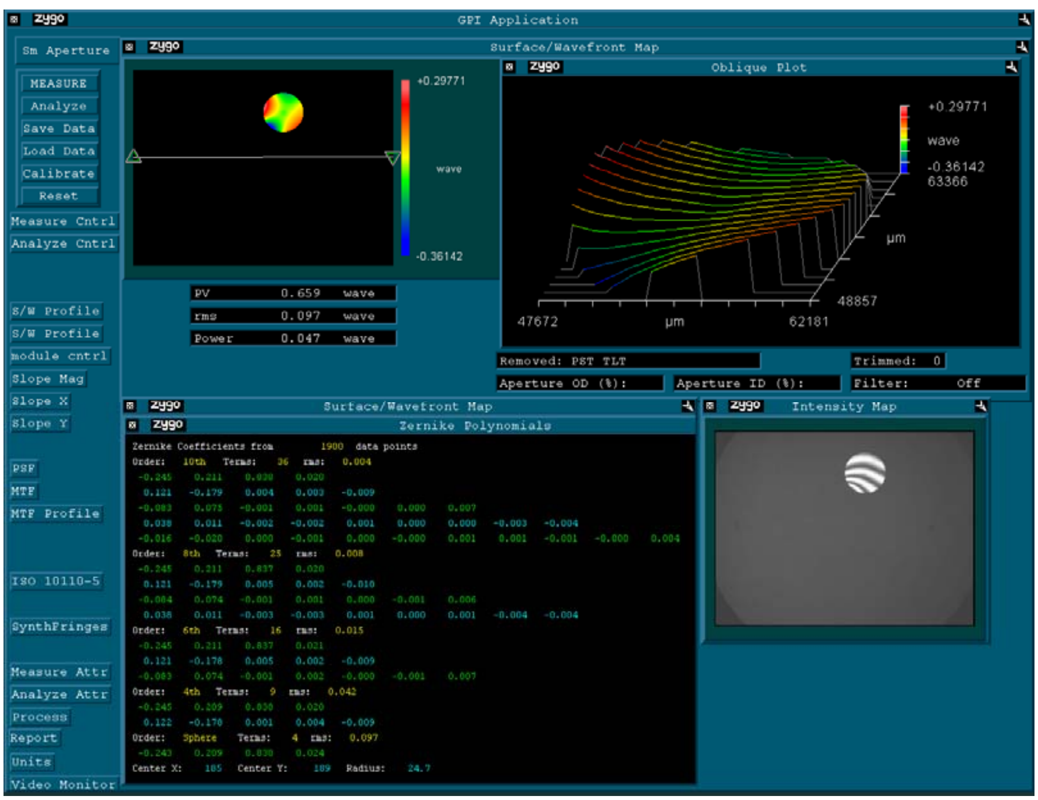
For these parameters, the engineer controls the interferometer with using 15mm diameter mask with 95% effective area.

At the initial state, we can find that there is some astigmatic on the surface, and the P-V value is about 0.671 waves, RMS value is about 0.098 waves.

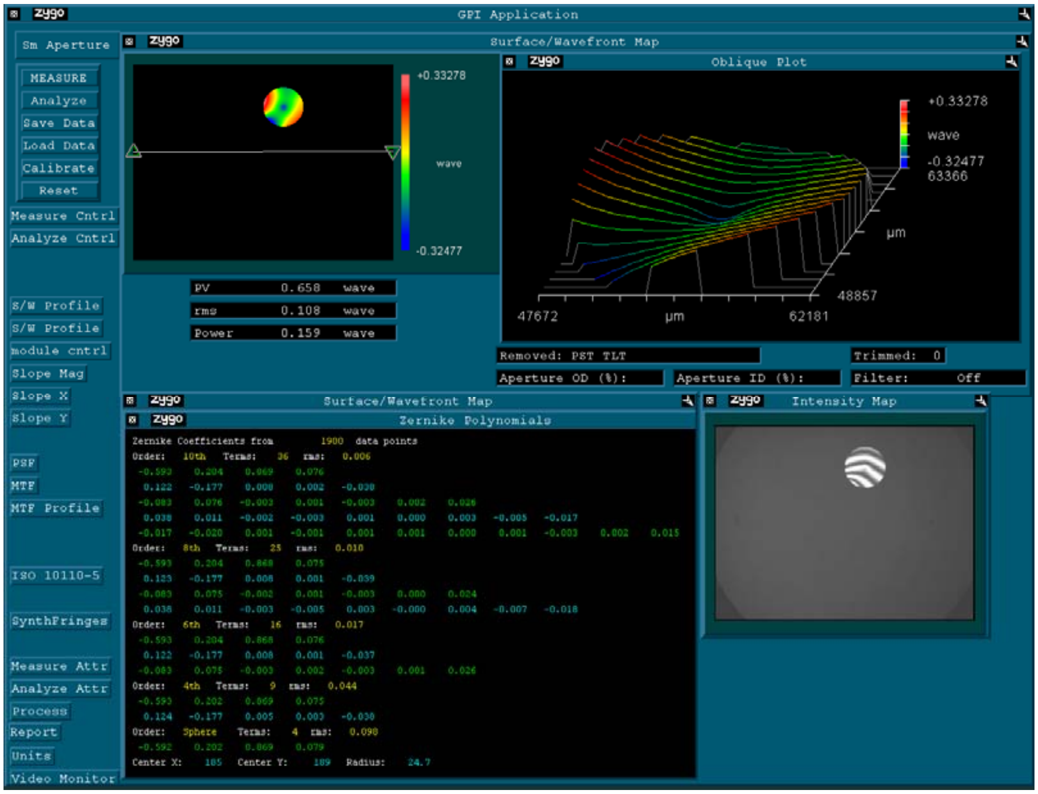
Testing result at initial state

Using same condition of the interferometer, we can get the Zernike coefficient of all channels.

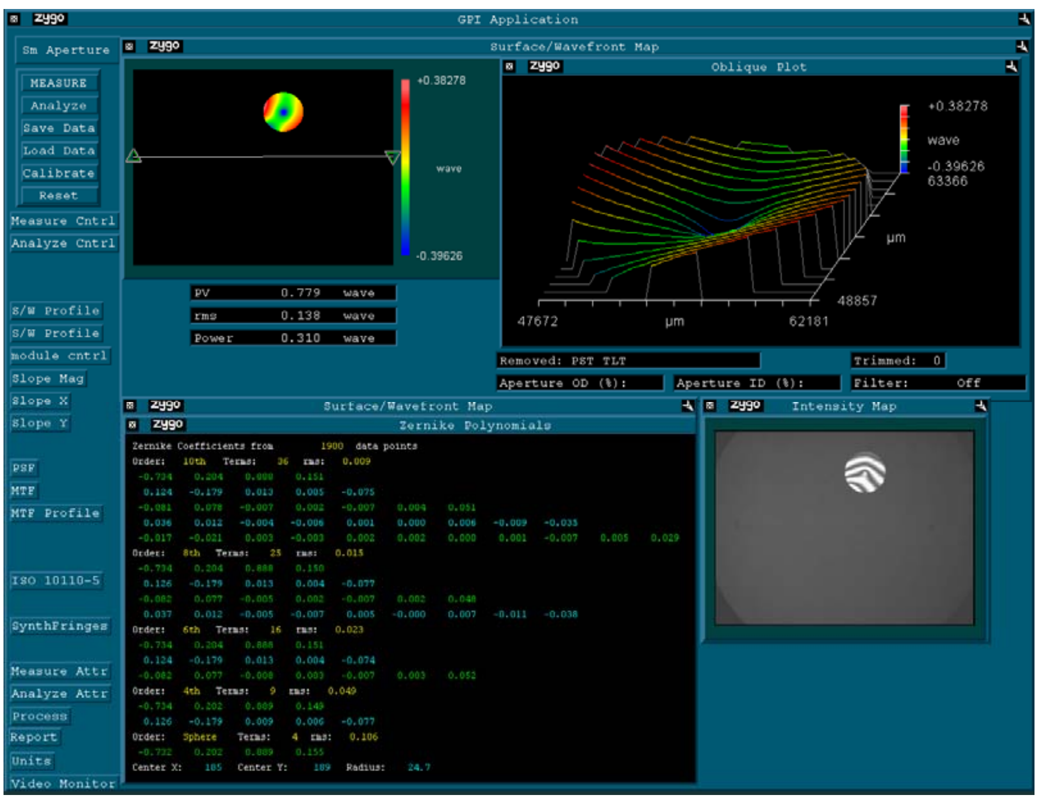
Here we use the channel one testing result as the example: the engineer control the channel one for four kinds of signal level as describe above (63, 127, 180 and 255) and recording the coefficient.



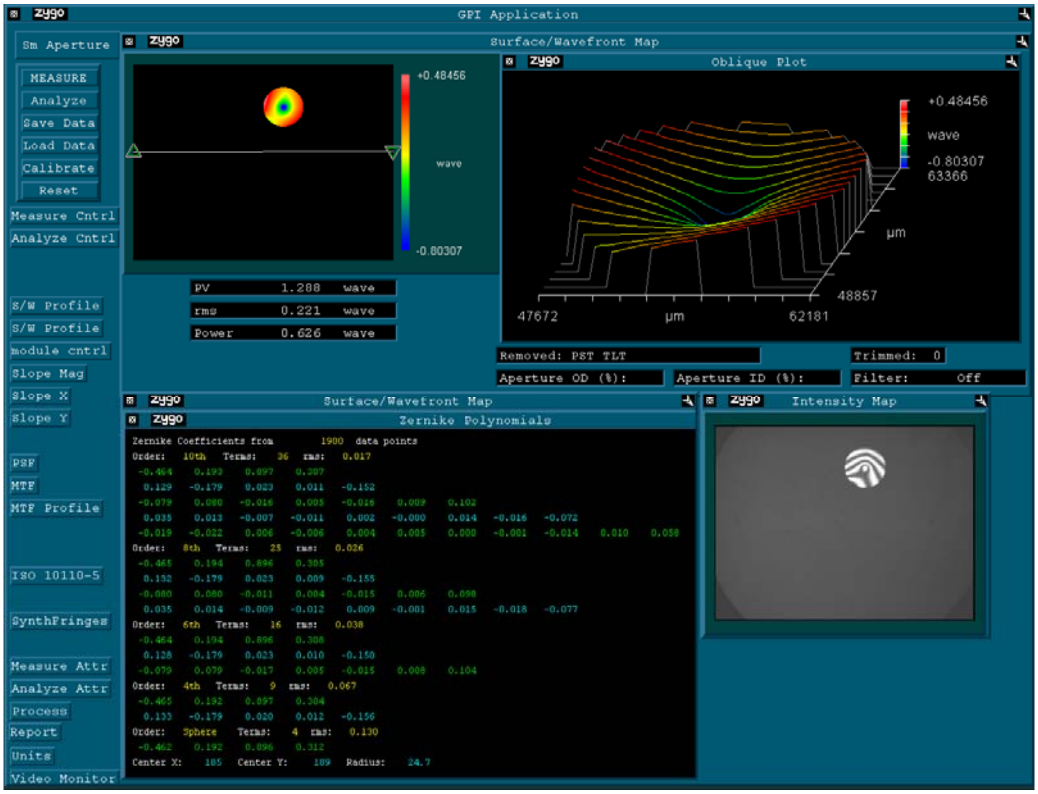
Testing result for channel at 63 signal level.



Testing result for channel at 127 signal level.



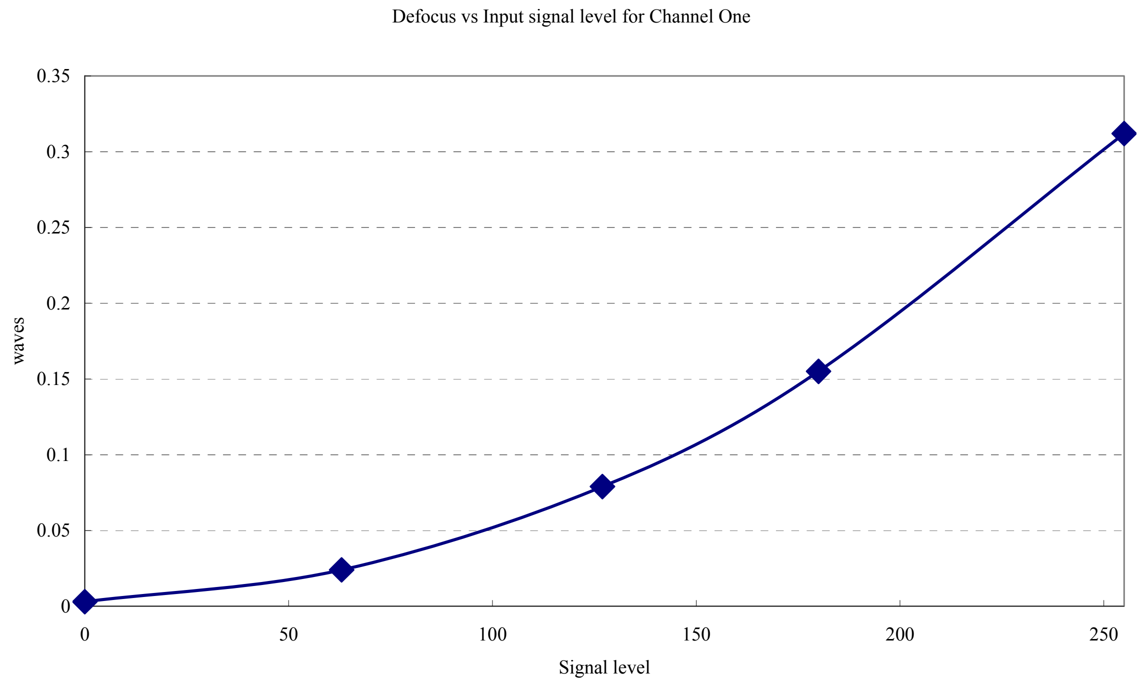
Testing result for channel at 180 signal level.



Testing result for channel at 255 signal level.

After getting the result, we can analysis the relationship between the Zernike coefficient and control signal level for each channel, for example we only consider the defocus aberration at the channel one, we can get following result:

Signal level	Zernike coefficient @ defocus (waves)
0 (initial state)	0.003
63	0.024
127	0.079
180	0.155
255	0.312



From the relationship describe above, we can find that the defocus is not perfect with the input signal level, so using the same analysis method the project team member can get the right way to control the deformable mirror and trying to compensate the aberration of human eye.

The reasons why we can not complete this project will be explained below. Two kinds of problems will be discussed. First is the technical problems, second is the budget issue. These two problems are conjugated to each other. Now we first explain the technical problems that we encounter during the whole project. The status of present system is that: we assembly a system according to the following system layout. During this project, we evaluate and review several deformable mirrors and purchase the deformable mirror from the OKO technology. We also build electronics power to drive the system, and we complete the system assembly that using and modified our existing components. Measurements of the deformable mirror are provided by the ITRI, and the information still under study. A system is build according to the characteristic of the deformable mirror. The principle of this layout is to try to minimize the size of the system, and we propose to use the microdisplay in this system. This microdisplay can produce several test chart and made the real time testing is possible.

During the testing, we put several standard lenses and measure the wave front. We found that it is possible to calibrate the system and give the answer of the power of the lens. Then we now using the mechanical holding to move the standard lens in a specific directions to produced artificial aberrations. We found that the feedback loop of the system can not work as we expected. After exam the system we realized that there are several problems. The first one is that the aberrations introduced by the system are large, especially by the camera lens. Second is the signal noise ratio of the system is not as good as we design. We using the 632.8 nm laser (not to human eye but only for testing) with appropriate attenuations. The pupils Vignetting will cause the problems during the H-S wavefront extractions algorithm since that the testing object is moving. (There is almost no problem if the object is stand still, but it is impractical for clinic exam).

After that we redesign the system and found that several components need to be purchased and replaced the present components that we can borrow from facilities. These components need to be replaced include relay Lens set, camera lens, CCD sensor, light sources with related collimation optics. After the optimizations, we found that the aberration caused by the system cab be reduced. Because the limitation of the AOARD budget which can't let us to have enough funds to complete the whole setting for delivery.

Second problems are the deformable mirror issues. Since we are building the driving circuits by ourselves, we found that there are some ad hoc designs in the circuit's pads. Before that we do not have the interferometers to test the mirrors as a benchmark, we stocks on the solving that problems between the optical layout and the driving issues. That took us some times and delay the whole schedules. So we asked the professional help from interferometer Lab of ITRI to test the performance of deformable mirrors. The test results is attached in the following paragraphys.

(5) Abstract

(A) We propose a basic system layout that combines with the microdisplay for contrast sensitivity function measurement. The optical components need to be modified to eliminate the aberrations.
(B) We made the power and control electronics for this system that increase the capabilities to build the specific deformable pattern by our self.
(C) We measured the interferences patterns for the deformable mirror and build the influences matrix
(D) We did **NOT** complete the system due the limited resources. It is believed that without appropriate financial management, it is not easy to complete the whole system in schedules.
(E) We have measured the interferences patterns of the deformable mirror with our driving power system. Preliminary results indicate that there might be some problems for the driving issues in the deformable mirror that leads to the slower or breakdown of the elimination of the aberration. Also, the reason that the optical components in this layout can not work perfectly is due to the large aberrations near the camera lens of the CCD and also part of the relay system. A modified design is accomplished.

(6) Personnel Supported

(A) Mr.Chang Chun Chung from Industrial Technology Research Institute, for his kindly assistance on the measurement of the deformable mirror using interferometer.
(B) Mr.Ray Ho from RayOpt Research in charge of the electronics devices for the Deformable Mirror
(C) Prof.K.L.Hunag from Husiping Institute of Technology (department of Electrical Engineering) involves the discussion of the aberration elimination procedures

(7) Interactions & News

Interactions:

(a) Participation/presentations at meetings, conferences, seminars, etc.

We present an oral report paper on the Annual Meeting of the Society of Information Display, Vision Section at the San Francisco (USA). Although we did not complete the whole system, but we report the application of the spatial light modulator (SLM) on this vision research. It is a very interesting and promising research topic. For example, it's well known that one can use the liquid crystal phase modulator or MEMS device in adaptive optics system for the aberration compensations [1][2], or virtual display technology [3]. In this article, we will report another application of SLM on the vision research – the test chart imagers. Conventional test chart are the images with specific patterns and contrast. But it is sometimes difficult to directly implement the measurement test chart with the specific devices. During our adaptive optics system project [4], we had been suggesting that using the LED mini projection system along with appropriate microdisplay imagers can be served as a more flexible method for testing the vision conditions. Figure.1 is the schematic layout of the adaptive system in our study. The purpose of this system is to correct the high order human eye aberrations, and the proposed microdisplay device is to help to detect the vision of the testers.

This section chairman is Dr.Eili Peli from Stephen Eye research, he also give some good comments about this device.

(b) Describe cases where knowledge resulting from your effort is used, or will be used, in a technology application. **Not all research projects will have such cases, but please list any that have occurred.**
None

News:

(a) List discoveries, inventions, or patent disclosures. (If none, report None.).

We proposed a system layout that combines with the adaptive system with the microdisplay for contrast sensitivity function detection. Now we are under contract with the local IP Company for patent issue.

(b) Completed the attached **"DD Form 882, Report of Inventions and Subcontractors."**

(8) Publications & Archival Documentation

Publications:

(a) C.R.Ou et.al., "Microdisplay as Vision Test Chart", SID2006, San Francisco, USA
(b) C.R.Ou et.al., "Construct Cornea Model for Intraocular Pressure Prediction after Refractive Surgery", 29^{th} Mechanical Conferences, National Tsing Hua University, Hsinchu, Taiwan (in Chinese)

Archival Documentation:

MicroDisplay Panel as Vision Test Chart Imager

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ABSTRACT

Microdisplay device is well known as high resolution imagers. In this study, we propose that using microdisplay as the vision test chart imagers. The measurements, such as vision acuity and contrast sensitivity, can be by using this kind of device.

Keywords: microdisplay, aberrations, adaptive optics, contrast sensitivity

INTRODUCTION

The application of the spatial light modulator (SLM) on the vision research is a very interesting and promising research topic. For example, it's well known that one can use the liquid crystal phase modulator or MEMS device in adaptive optics system for the aberration compensations [1][2], or virtual display technology [3]. In this article, we will report another application of SLM on the vision research – the test chart imagers. Conventional test chart are the images with specific patterns and contrast. But it is sometimes difficult to directly implement the measurement test chart with the specific devices. During our adaptive optics system project [4], we had been suggesting that using the LED mini projection system along with appropriate microdisplay imagers can be served as a more flexible method for testing the vision conditions. Figure.1 is the schematic layout of the adaptive system in our study. The purpose of this system is to correct the high order human eye aberrations. During the correction (or introduced) of the human eye aberrations, it is required to precede the contrast test chart exam to study the vision qualities. In this optical system, we use the microdisplay device to project the specific image patterns to the human retina. Several types of panels system had been introduced for the present apparatus to study the feasibilities of this kind of exam procedures.

There are various kinds of vision test charts for clinical investigations. The acuity test chart can examine the size effects, and the contrast sensitivity chart can exams both the size effects and the influences of the contrast ratio.

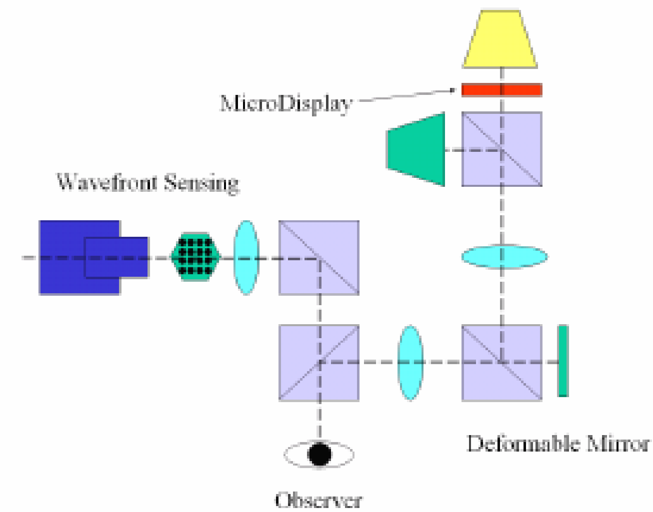

Fig.1 System layout with adaptive optical system

Figure.2 is one of the contrast sensitivity test chart that we had been use during our experiments. Other types of test chart such as CSV1000 series from Vector Vision are also recommended. It is clear that a well designed imaging system is required to display this test chart, otherwise the crosstalk and degradation issues [5, 6] will leads to misjudgment of the observers' vision.

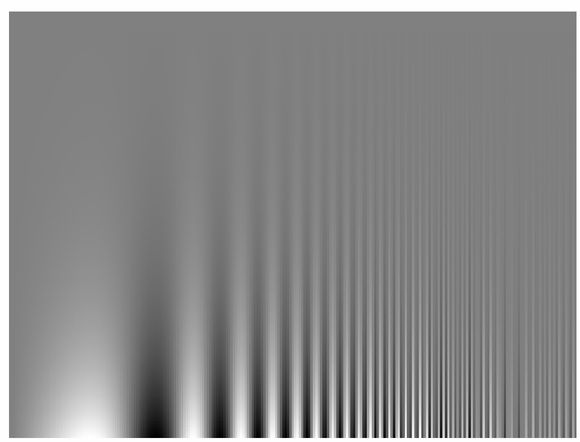

Fig.2 Contrast Sensitivity Pattern

As a summary, the purpose of this study is to present a system which can evaluate the vision capabilities, as part of the adaptive optical system that we made. We intend to use MEMS type deformable mirror to introduce or to eliminate the human eye aberrations (Zernike terms). By using microdisplay, we can evaluate the effects on these aberrations to the vision perception.

EXPERIMENTS

Panel

Due to the requirement on the high qualities of these testing images for the clinical purpose, we propose several approachesthat using different microdisplay device. We had been tested these different approaches and found that some of them could not perform some specific patterns in great details. The high frequency signal problem is always an issue. One of these approaches is the system from our previous mini projector project [7]. The advantage for that system is the compact size, such that the vision inspection module can be easily insert into the whole adaptive system. But the LCOS panel along with our system can not provide very good qualities. The current problem for most LCOS system (we can purchase) is the contrast issue. The second solution is to use the commercialized SONY LCD panel system. Although the system is much larger than the previous one, but the image qualities are much better. After the evaluation, we consider that the SONY LCD system can meet the experiment requirements. It need to be mention that the DLP system can have a very excellent contrast ratio, but it is not easy for us to direct integrate it into the system without a specific design modules, either electrical or optical point of view. Since DLP is a very promising device, we are now evaluating to apply the DLP type MINI projector into our system. The finest Pattern produced by the microdisplay panel is the interlaced pattern with only one pixel space (highest frequency square wave pattern). The current pixel size will lead to about 20 lp/mm image resolutions. Within a 10 degree viewing angle system design for the microdisplay test chart imager (F#~5.7), the maximum resolutions that we can achieved is equivalent to 50 lp/deg. In our system, a slow system can eliminate most of the system aberrations and optical noise (stray-light), which can provide a more reliable environment for the vision research (this is because the vision model does take into account the photon noise factor). With 3mm eye pupil size, according to the principle in physics optics (i.e. 1.22λ/D) the resolution angle of the normal observers is around 1 arc min. Through the above discussions, we can determine the required dimensions for the system.

Contrast Sensitivity

There are a lot of experimental works on the measurements of the contrast sensitivity (Chapter 3 in [8]). Complete model for contrast sensitivity of monocular vision, which is very helpful for designing our experiment system, can be described by equation (1). Details on the physical meaning of these parameters and their conventional numerical values can be found in [8]. This equation also can provide a very excellent fit to the measurement data, such as the one done by Campbell & Robson (1968) under 500 nits conditions.

$$S(u) = \frac{1}{m_t(u)} = \frac{M_{opt}(u)/k}{\sqrt{\frac{4}{T}\left[\frac{1}{X_0^2} + \frac{1}{X_{max}^2} + \frac{u^2}{N_{max}^2}\right]\left[\frac{1}{\eta p E} + \frac{\Phi_0}{1 - e^{-(u/u_0)^2}}\right]}} \qquad (1)$$

In the present study, photopic viewing condition is assumed for both the calculations and experiments. The Stiles-Crawford effect is then taken into account to modify the quantity of the retinal illuminance. The value X0 in this model is 10° as the object size of the microdisplay panel. Since the pupil diameter will vary with the average luminance, Bouma’s equation (1965) is adopted.

Although our current results (which will be shown later) are not perfect match with this model, we consider equations (1) can be taken as a bench mark. Therefore, by using the appropriate system design, one can make the most benefit on the designing of the microdisplay based image test chart system. Figure.3 is the present experiment system. There are four parts of the system:

(A) adaptive optical system
(B) tunable LED light source
(C) microdisplay modules
(D) measurement & monitoring modules

The influences of the specific aberrations on the vision perceptions will be discussed in details on appropriate publications. The LED light source from Alliance-Optotek (Taiwan) [9] provides a better thermal solution, which can meet the requirement of uniform lighting qualities between the different testers. The brightness of the LED can be adjusted to reveal the effects of brightness to the vision perceptions. Different combination of the LED light source can be considered as a scanning source to study the vision response dynamically. Finally, the non-uniformity of the illumination system might lead to the degradation of the image qualities. Criterions that based on [6] are under study.

Fig.3 Experiment system

RESULTS AND DISCUSSION

Up to March (2006), 3 testers (▲25 yr, ■35 yr and ●38 yr) with both eye partially correct visions were invited to precede the contrast sensitivity experiments. There are 12 data after the experiment (3 testers with 4 different spatial frequency patterns), but it should be note that one of the testers (●38yr) with higher astigmatism aberrations, seems to have problems to decide the modulation threshold in our device, which affects the final results. Results are shown in Figure.4. At the present moment, these measurement data are not perfectly matched with the model. Improvements will be update before this oral section. Our experiments show that the conjugate locations between the microdisplay panels and the pupils are highly sensitivities. The measurement errors are also strongly influences by the alignment of the system between microdisplay and the observers. The errors are more than we expected.

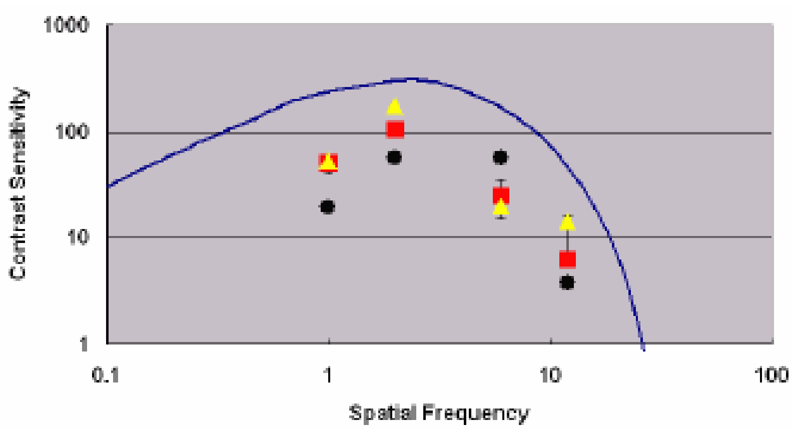

Fig.4 Present results (up to 2006.2.20)

CONCLUSION

Preliminary results, which using the microdisplay panel as vision testing charts, are reported. Although the comparison between the experiment and model is not perfect at the present moment, our evaluation indicates that it is possible to use microdisplay for clinical instrument for vision research. Any Improvements on the experiment results will be report on the oral section.

ACKNOWLEDGEMENT

The authors would like to thank to the support from Dr.Brian Chou (USAF). We also appreciate the technical support from RayOpt Research (Taiwan).

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(9) Software and/or Hardware

(A) Two deformable mirrors
(B) Two H-S masks
(C) One CD disk for driving Software
(D) Two PCI cards for 40 channels